AN EXPLORATION OF THE RELATIONSHIP BETWEEN STREET PATTERNS AND FLOODPLAINS IN THE WOODLANDS, TEXAS

A Thesis

by

JUNPING XU

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF URBAN AND REGIONAL PLANNING

August 2009

Major Subject: Urban and Regional Planning

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Approved by:

Chair of Committee, Elise M. Bright
Committee Members, Robert S. Bednarz
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ABSTRACT

An Exploration of the Relationship between Street Patterns and Floodplains in The Woodlands, Texas. (August 2009)

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Chair of Advisory Committee: Dr. Elise M. Bright

The objective of this thesis is to explore the relationship between street patterns and floodplains. Although some researchers have written about the relationship between land use and floodplains in The Woodlands, few have discussed how the city form was designed around the hydrological system. This thesis will focus on one aspect of the city form, the street pattern, to determine the effectiveness of street designs' response to floodplains.

Unlike the grid-like pattern advocated by the New Urbanists, street patterns in The Woodlands are loops and cul-de-sacs -- a typical suburban pattern at the time it was developed; however, street patterns adapt to the boundaries of floodplains and protect them very well. Using a GIS tool to overlay 100-year floodplains on the street layer, it is clear to see that there are low percentages of streets in the 100-year floodplains. Thus, The Woodlands employed nonstructural techniques to mitigate flood hazard, which minimize the development in floodplains. Flood control in The Woodlands is much better than other places in the Houston area.

From flood control and the protection of the natural environment standpoints, the nonstructural techniques are advocated more than structural techniques for floodplains in

the development management. Therefore, the design of street patterns in an area is determined by both the aim of convenient transportation and the aim of hazard mitigation.

ACKNOWLEDGEMENTS

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I deeply appreciate my family. Without my parents' great support, I could not have finished my studies smoothly. Studying in the U.S. was their dream when they were young; however, historical circumstances handicapped them. I am glad that I can have the opportunity to achieve their dream. Thanks to all my dear friends; without you, I really do not know how I would have adapted to the new environment.

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CHAPTER I

INTRODUCTION

1.1 Research Background

Since the 1960s, there has been a growing awareness of the need to bring environmental values to the urban development. McHarg, Lewis and other supporters called for that ecological process provide the indispensible basis for planning and design (Hough, 1984). The Woodlands in Montgomery County, Texas is the application of the "Design with Nature" philosophy by McHarg.

The Woodlands is a master-planned 27,000 acre community of mixed use. It is in the Houston–Sugar Land–Baytown metropolitan area, located 28 miles north of Downtown Houston along Interstate 45(Figure 1.1) (Galatas and Barlow,2004). The Woodlands was the first environmentally planned community in the U.S. (Morgan and King, 1987). In fact, The Woodlands Development Corporation accomplished the first Environmental Impact Statement in the United States before it was legally required (Morgan and King, 1987). The Woodlands is different from other communities built at that time because it applied ecological methods into development and protected the hydrological system well (Morgan and King, 1987).

Located in the Gulf Coast Plain, The Woodlands has flat topology with clay soil. Although the site was covered with forests--an ideal place to live-- it is a hard environment to build in (Galatas and Barlow, 2004). The site is flat with few slopes

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greater than few slopes greater than five percent (Johnson and Berger, 1979). Almost one third of the site is in the 100-year floodplains of Panther, Bear and Spring Creek (Johnson and Berger, 1979). The Panther Creek runs through the area with many wadies and one perennial stream (Johnson and Berger, 1979). Impermeable soils and standing water create many depressions in the flat terrain (Johnson and Berger, 1979). Thus, the drainage from storm runoff was poor on the site.

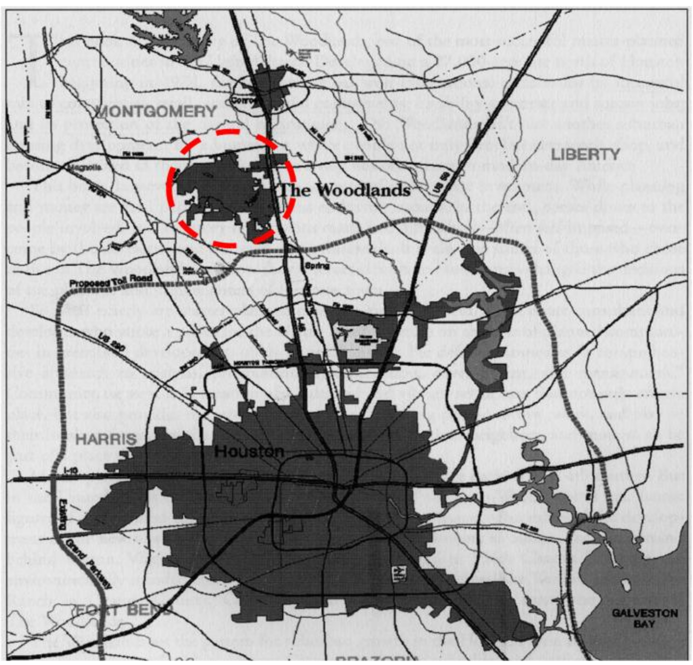


Figure 1.1 The location of The Woodlands, Texas

Source : Galatas and Barlow,2004

This research will discuss two aspects of the master planning in The Woodlands: street patterns and floodplains.

From the general plan of The Woodlands (Figure 1.2 and Table 1.1), we can see that the community was divided into several villages. The developers followed a typical suburban pattern when they designed lots for homes at that time. Almost all developing lots are in cul-de-sacs, enclosing a few houses instead of long and straight streets (Galatas and Barlow,2004). Homeowners like this kind of street pattern because extensive use of cul-de-sacs slows down car speed and makes walking and biking safer (Galatas and Barlow, 2004).

The most serious problem facing the designers was “much of the site is poorly drained and there is standing water after rains. Streams have very low base flows and shallow floodplains in the flat topography” (Hough, 1984, p99). Nearly one third of the site is in the 100-year floodplains, which is an important characteristic for the site planning. “It also became apparent that the introduction of conventional piped storm drainage would destroy much of the forest landscape” (Hough, 1984, p99).As a result, the development was shaped to the hydrological determinants (Hough, 1984).

The connectivity of street patterns in The Woodlands and their protection of floodplains are research questions that will be discussed later.

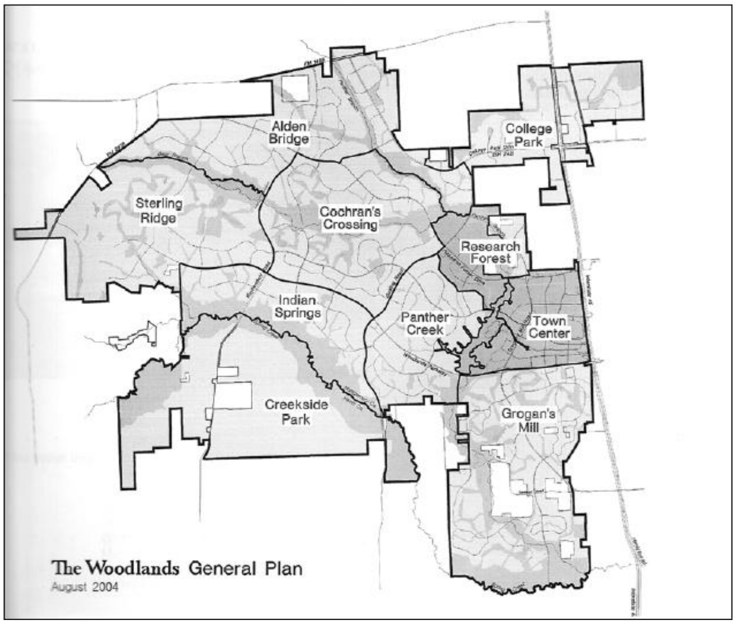


Figure 1.2. The general plan of The Woodlands, Texas

Source: Galatas and Barlow, 2004

Table 1.1 The open year of villages

Village of Grogan's Mill:	1974
Village of Panther Creek	1976
Village of Cochran's Crossing	1983
Village of Indian Springs	1984
Village of Alden Bridge	1993
Village of College Park	1995
Village of Sterling Ridge	2000
Village of Creekside Park	2007

Source: Galatas and Barlow, 2004

1.2 Research Objective

The Woodlands, Texas provides an excellent example of ecological planning. As a low density suburban development area, it adapts well to natural conditions. Heavy seasonal rains result in frequent flooding of streams. Much of the site is poorly drained because “streams have very low base flows and shallow floodplains in the flat topography” (Hough, 1984, p99). McHarg called for the establishment of a natural drainage system in the form of floodplains, swales and ponds (Johnson and Berger, 1979). Nearly one third of the site is in the 100-year floodplains, which influences the site planning critically. Thus, this thesis will focus on floodplains.

Although some researchers have written about the relationship between land use and floodplains in The Woodlands, few have discussed how the city form was designed around the hydrological system. This thesis will focus on one aspect of the city form, the street pattern, to determine the effectiveness of street designs’ response to floodplains. The street pattern in The Woodlands is a typical conventional development pattern, loop and cul-de-sac. New Urbanists advocate the gridiron street pattern more than the loop and cul-de-sac. However, the consideration of street pattern response to floodplains and flood control may not be included in the New Urbanism concepts. To strengthen the conclusion, this thesis chose another city in Houston area, Pearland, which has a similar flood hazard situation. Most street patterns in Pearland are gridiron patterns. Through comparison, we could find that the evaluation of street design in New Urbanism concepts needs to incorporate more consideration of environmentally sensitive natural areas.

This research will bring a new standpoint to understand the relationship between urban form and urban ecology.

1.3 Thesis Structure

This thesis has six chapters as follows**:**

Chapter I is the introduction which provides the research background information and discusses the research questions. This chapter explains the research objectives, and the research values are also highlighted.

Chapter II reviews the major literature for related issues. In the first part, it generalizes the hydrological issues in the ecological planning of The Woodlands. The evolution of the urban form is presented in the second part.

Chapter III defines the research variables: street patterns and floodplains.

Chapter IV provides the ideas about how to design the research and introduces the research method used in this thesis. Data collection and analysis are also included in this chapter.

Chapter V is the most important part of this thesis: measuring street patterns in The Woodlands and analyzes the relationship between street patterns and floodplains.

Chapter VI generalizes the findings and analysis in the research and gives suggestions for future research.

CHAPTER II

LITERATURE REVIEW

This chapter discusses a comprehensive review of relevant literature for this study. In the first part of the literature review, it focuses on the hydrologic issues in ecological planning guidelines applied in The Woodlands. The second part provides discussion on the evolution of the urban form.

2.1 The Hydrological Issues in the Ecological Planning of The Woodlands, Texas

The Woodlands in Texas was the first master-planned community employed an ecological approach in the 1970s (Galatas and Barlow, 2004). Its master plan was heavily influenced by a team from the Philadelphia firm led by Ian McHarg. “Originally planned for 150,000 people on 15,000 acres, the project land use has expanded to 27,000 acres. In the 2000 census, its population had reached 56,000” (Forsyth, 2003, p10).

The first flow of residents found that the new community was different from others in the Houston area when they moved into The Woodlands in 1974 (Galatas and Barlow, 2004). The planners of The Woodlands had a high respect for the environment. One of the consultants hired by George Mitchell was a famous ecologist and landscape architect, Ian McHarg. His book ‘Design With Nature’ was considered the best book for guidelines on limiting the impact on the natural landscape when designing new communities. Both Mitchell and McHarg realized that, if not developed correctly, the relative flat site and heavy rains, especially during hurricanes and tropical storms, often result in flooding in The Woodlands (Galatas and Barlow, 2004). Keeping the forest and green floor will provide a natural flood barrier.

Ian McHarg, “a Scottish-born landscape architect with a master’s degree in planning, was interested in working out more systematic ways of analyzing and designing the natural system for creating overlays of physical, biological, and social features--eliminating from development areas of high value” (Forsyth, 2003, p12). His ecological design approach relied on a rational method, “progressing logically from ecological data inventory to interpretation, assessment of landscape tolerance, design synthesis, guidelines, and plans” (Forsyth, 2003, p12). This approach is demonstrated by the environmental planning in The Woodlands.

In the opportunity of planning The Woodlands, McHarg applied his ecological ideas to decide what kind of development could and should take place (Galatas and Barlow, 2004). A detailed study of the land took place and determined two major ecological functions. One of them is the hydrologic system. Reducing the runoff and using natural systems were the major objectives (Forsyth, 2003). “ The regional water management commission wanted to maintain the recharge of the city of Houston’s groundwater supply” (Johnson and Berger, 1979, p255). “Recharge of water was of primary importance to diminish the risk of subsidence on the site as well as down dip in Houston. Additionally, groundwater was planned as a means of augmenting baseflow in the creeks to enhance the amenity value of artificial lakes to be constructed on the site” (Johnson and Berger, 1979, p252).

Flood hazard was the only natural hazard in The Woodlands. "Development along major streams inundated by the projected 100-year flood in this site was preempted" (Johnson and Berger, 1979, p258). "In addition to the use of some soils as sinks for high-frequency storm drainage, a system of naturally occurring swales and stream corridors supplemented with man-made swales was designed to carry storm runoff from the low-frequency events" (Johnson and Berger, 1979, p258). "Development in the 25-year flood zone of the smaller drainage ways was also preempted. The swales and stream corridors were left in a vegetated condition which helped preserve the woodland environment and maintain corridors for wildlife movement" (Johnson and Berger, 1979, p260).

In the book The Woodlands, New Community Development, 1964-1983 outlined seven goals that McHarg established for The Woodlands master plan, including "minimum disruption of the hydrological regimen of the ground plane's surface and subsurface" (Galatas and Barlow, 2004, p35), and "establishment of a natural drainage system in the floodplains, swales, ponds and soil capable of absorbing rain" (Galatas and Barlow,2004, p35).He also expressed his belief that the site offered unique opportunities for innovative storm-drainage, sewage and transportation systems.

Although the urban development impacts the landscape and natural processes, minimum disruption of the hydrologic cycle is possible (Johnson and Berger, 1979). In The Woodlands development scheme, "recharge is maximized, exacerbation of flooding by development minimized, the groundwater and baseflow to streams augmented [compared to] conventional drainage, and erosion hazard reduced due to vegetated drainage ways" (Johnson and Berger, 1979, p262).

2.2 The Evolution of the Urban Form

During particular historical eras, there were specified urban forms to be constructed (Wheeler, 2003). "Each era's unique type of development covers substantial portions of the metropolitan landscape with distinctive street networks, land use mixtures, block and street designs, distributions of park space, lots and housing forms"(Wheeler, 2003,p318).

In the past, several primary patterns of urban form have emerged at different historical periods. These morphological phases include mid 19th-century grids, streetcar suburb grids, garden suburbs, automobile suburbs and New Urbanism (Wheeler, 2003).

(1) Nineteenth-century Compact Grids

In the late 18th and early to mid 19th centuries, grid patterns with relatively small and square blocks emerged in most cities of North America (Wheeler, 2003). It was easy for landowners, speculators and railroad companies to layout and subdivide lands into saleable parcels (Wheeler, 2003).

(2) Streetcar Suburb Grids

In the 1870s and 1889s, a new morphology emerged in North America "in response to the advent of horse-drawn streetcars by 1870 and electric streetcar service in the 1880s. The new streetcar suburb grid featured regular rectangular blocks, somewhat larger block sizes and a typical placement of shops in nodes along streetcar corridors" (Wheeler, 2003, p320).

(3) Garden Suburbs

Frederick Law Olmstead, Calvert Vaux and Andrew Jackson advocated garden suburb ideas after the turn of 20th century. "A few individual projects in most large cities in the late 19th century had experimented with these ideals" (Wheeler, 2003, p321).

(4) Automobile Suburbs

Due to the economic depression and World War II, during the 1930s and 1940s, there were few developments in the city around the United States (Wheeler, 2003). "Grid forms continued to degenerate and small-scale, haphazard development expanded the urban footprint" (Wheeler, 2003, p322). However, after World War II, "with the post-war arrival of widespread automobile ownership, an economic boom and new large-scale housing production techniques, a new metropolitan form was added in the decades after World War II. Developers began to experiment with curvilinear street forms, new block and lot layouts, and new architectural styles and landscaping The public sector enabled the new dominant urban form through the provision of infrastructure, preparation of planning documents, zoning, building and street design codes" (Wheeler, 2003,p322).

(5) The New Urbanism

At the end of the 20th century, The suburban development patterns were opposed by the New Urban concepts throughout North America(Wheeler, 2003).The new urban form principles had emerged, “emphasizing regional growth management, downtown revitalization, walkable neighborhoods and mixed-use and transit-oriented development” (Wheeler, 2003,p322). The New Urbanism and Smart Growth are responses to sprawl, which demonstrated new values of urban form.

CHAPTER III

STREET PATTERNS AND FLOODPLAINS

3.1 Street Patterns

3.1.1 The Definition and Topologies of Street Patterns

The street can be seen as a road that happens to have urban characters and serve as a right of way (Marshall, 2005). It is an important physical element in city design. The street is not only an urban road, but is multi-functional urban space (Marshall, 2005).

According to the function of transportation, the streets can be classified by various predominant activities (see Table 3.1). Another approach can be used to classify the streets based on the urban design literatures (see Table 3.2).

Table 3.1 The street hierarchy of transport in the urban environment

Road type	Predominant activities
Primary distributor	Fast moving long distance through traffic. No pedestrians or frontage access
District distributor	Medium distance traffic to primary network. Public transport services. All through traffic between different parts of the urban area
Local distributor	Vehicle movements near beginning or end of all journeys
Access road	Walking. Use of highway by frontagers. Delivery of goods and servicing of premises. Slow moving vehicles
Pedestrian street	Walking. Meeting. Trading
Pedestrian route	Walking. Some cycling in shared space
Cycle route	Cycling

Source: Marshall , 2005.25

Table 3.2 The street hierarchy of urban design literatures

Conventional	Suggested street types that combine capacity and character
Primary distributor	Main road – routes providing connections across the city
District distributor	Avenue or boulevard – formal, generous landscaping
Local distributor	High street – mixed uses, active frontages
Access road	Street or square – mainly residential, building lines encouraging traffic calming
Cul-de-sac	Mews/courtyard – shared space for parking and other uses

Source: Marshall, 2005. 26

The street pattern is a kind of settlement pattern and can be defined as the shape and structure of the streets (Marshall, 2005).The topologies of street patterns have different classifications based on various issues. There are two major issues related to street patterns: Urban Design and Transportation Network. Table 3.3 shows topologies of street patterns based on the two issues.

Table 3.3 The topologies of street patterns

Urban Design Related Transport Network Related	Urban Design Related Transport Network Related
City design according to artistic principles 1. Rectangular 2. Radial 3. Triangular	Traffic planning and engineering 1. Gridiron 2. Linear 3. Radial
Town and country planning 4. Gridiron 5. Hexagonal 6. Radial 7. Spider's Web	Transport Technology and Network Structure 1. Spinal and tree 2. Grid network 3. Delta Network
Site planning 1. Grid 2. Radial 3. Linear	Road System Design 1.Radial and circumferential 2.Grid 3.Hyperbolic Grid
Good city form 1. Axial network 2. Capillary 3. Kidney 4. Radio-concentric 5. Rectangular grid	Transport Network Analysis 1.Path 2. Tree 3.Cycle
AIA guidance 1. Curvilinear 2. Diagonal 3. Discontinuous 4. Grid with diagonals 5. Organic 6. Orthogonal	Traffic Engineering and Management 1.Grid 2.Tributory

Source: Marshall , 2005. P78

3.1.2 The Comparison of Primary Street Patterns

Properly designed streets could produce a safe, quiet and healthy living environment. Therefore, street design contributes to the quality and feature of a community (Marshall, 2005). There are two primary street pattern types: the conventional suburban loop and cul-de-sac pattern and the grid pattern (Marshall, 2005).

Figure 3.1 displays the evolution from traditional grid pattern to cul-de-sac patterns from 1900 to the present.

The conventional suburban street pattern, the loop and cul-de-sac, was shaped by the mode of transportation and explosion of city growth. Nearly all the urban edges were made equally accessible for people to arrive when the emergence of automobiles as personal transportation was popularized around the county in the 1970s (Marshall, 2005). However, this kind of street pattern encourages driving not walking. Nowadays, the New Urbanists advocate the grid patterns because they have higher connectivity and encourage walking, which seems to be a kind of pattern for sustainable development. Although the loop and cul-de-sac street pattern has weaknesses when compared to the grid pattern, it still has advantages in some aspects.

From Figure 3.2, it is easy to see that the loop and cul-de-sac street pattern conserves 12.3 percent more area for streets and, as a result , 12.3 percent more buildable area than the grid pattern. Thus, the loop and cul-de-sac street pattern conserves more land than that of the grid pattern.

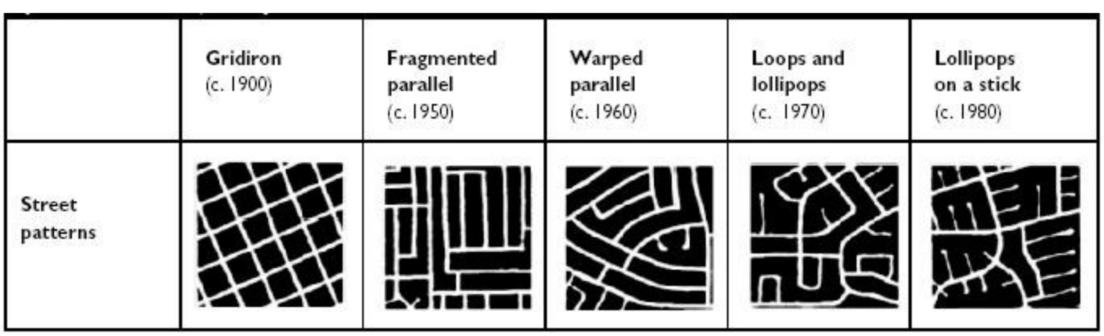
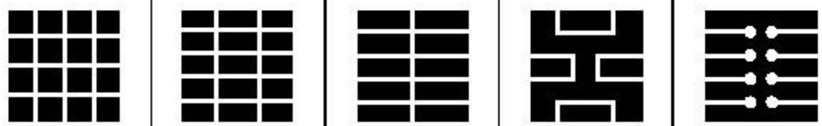


Figure 3.1 The evolution of street patterns since 1900

Source: Grammenos, 2002.



	Square grid (Miletus, Houston, Portland, etc.)	Oblong grid (most cities with a grid)	Oblong grid 2 (some cities or in certain areas)	Loops (Subdivisions - 1950 to now)	Culs-de-sac (Radburn - 1932 to now)
Percentage of area for streets	36.0%	35.0%	31.4%	27.4%	23.7%
Percentage of buildable area	64.0%	65.0%	68.6%	72.6%	76.3%

Figure 3.2 The comparison of area used for streets, among five typical patterns

Source: Grammenos, 2002.

The primary role of streets is transportation. We could analyze transportation situations within the two kinds of patterns (see Table 3.4). The loop and cul-de-sac street patterns are designed for automobiles and the distance is too great for walking. The grid street pattern limits the speed of automobiles and provides the opportunity to walk.

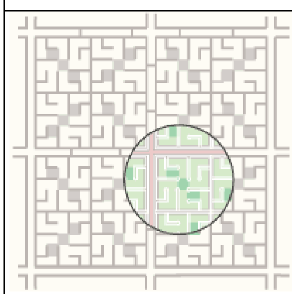
Table 3.4 The comparison of traffic situations between two street patterns

The type of street pattern	**The comparison of the traffic situations**	**Conclusions**
The Grid Pattern	(1)At each grid corner, there are 16 possible intersecting paths. The priority has to be deciphered by the driver or controlled by traffic lights. (2) Grid intersections occur at every 200 feet, or every 6 to 8 seconds at typical car speeds. (3) Good connectivity to encourage walking.	It undermines the car's primary advantages—speed, however, it has clear orientation and good connectivity.
The Loop and Cul-de-sac Pattern	(1)T-intersections have only 3 intersecting paths, where priority is easily grasped. (2)The congestion of loop and cul-de-sac generally caused by the concentration of homogenous land uses. (2) Their curvilinear aspects lengthen and confuse walking	Street patterns like the loop and cul-de-sac, which are designed for the automobiles, are poorly adapted to pedestrian traffic.

Source: Grammenos, 2002.

For residents, the loop and cul-de-sac pattern and grid pattern both have their distinct advantages. Streets with loops and cul-de-sacs provide a safe, social and efficient environment for people; while grid patterns offer connectivity and easy orientation. Thus, a new street pattern emerges, fused pattern, combining the advantages of the two patterns together (see Table 3.5).

Table 3.5 The comparison between typical street patterns

 **Grid**	• Direct, convenient routes throughout and better connectivity than the Cul-de-sac pattern • More paved area for roads • Many fourpoint intersections in residential areas make walking less safe.
 **Cul-de-sacs**	• Long routes to get short distances • Less paved area • Open space beyond walking distance for most residents.
 **Fused pattern**	• Continuous open network of pedestrian-friendly streets, paths and open spaces • Less area for roads than traditional grid • Easy pedestrian access from residences to surrounding businesses and public facilities • Close proximity to open spaces.

Source: Carpenter and Fick, 2005.

3.2 Floodplains

3.2.1 The Definition of the Floodplain

"Floodplains are wetlands which oscillate between terrestrial and aquatic phases" (Junk, 1997 , p3) It is "the relatively flat lowland that borders a river, usually dry but subject to flooding . Floodplain soils actually are former flood deposits" (Dinicola, 1997, p2). The floodplain includes the floodways, carrying floodflows, and the flood fringe (see Figure 3.3).

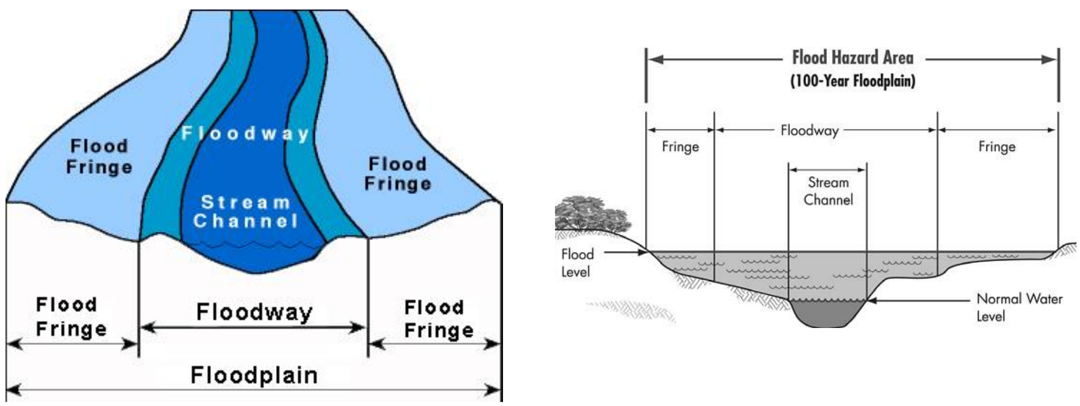


Figure 3.3 The sections of the floodplain

Source: http://maps.google.com

"The term '100-year flood' is really a statistical designation, and there is a 1[percent] chance that a flood this size will happen during any year. Perhaps a better term would be the '1-in-100 chance flood' " (Dinicola, 1997, p2).It is the similar to the definition of the 500-year floodplain, which has a 0.2 percent chance of flooding the designated area.

3.2.2 Strategies of Flood Control in The Woodlands, Texas

Urbanization is a tendency for flash floods. "There are caused by large areas of imperious paving and the concentration of water flows to specific points." (Hough, 1984, p71). The flood hazard, as shown in the inventory of The Woodlands, is the only natural threat in the area to peoples' lives and health (Johnson and Berger, 1979).

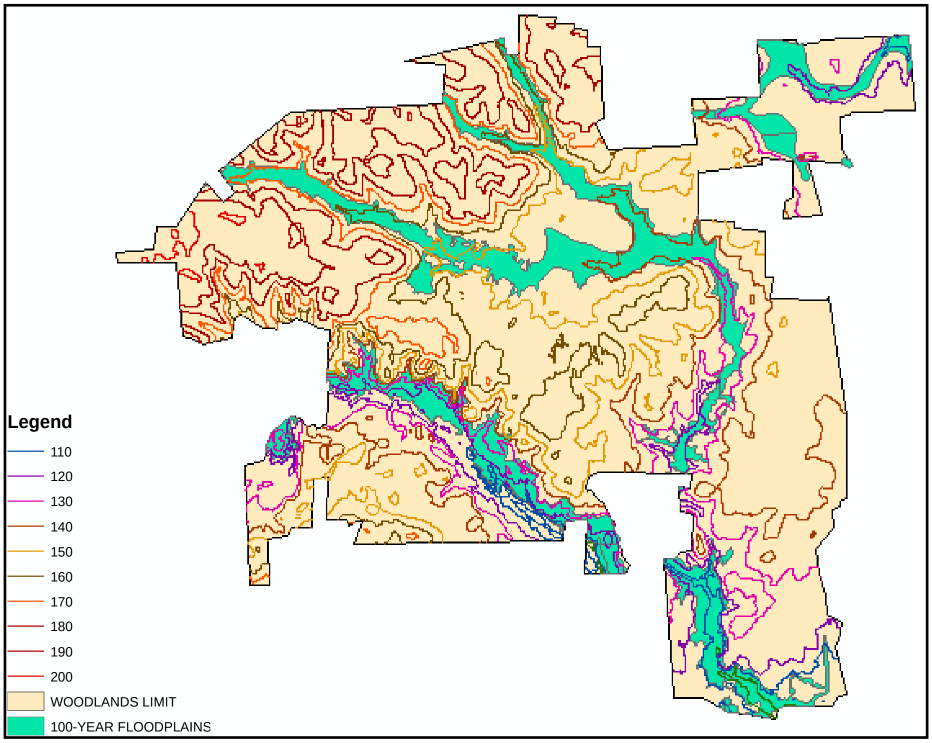
"Spring Creek and lower Panther Creek are the only perennial streams within the site. The others are intermittent, flowing during periods of storm runoff" (Johnson and Berger, 1979, p252). Intensively mixed woodlands, flat topography and imperfectly drained soils are primary characters of The Woodlands (Hough, 1984). Located in the subtropical area, heavy seasonal rains result in the frequent flooding of streams. Most of the site is poorly drained and, after heavy rain, there is standing water on the ground. "Steams have very low base flows and shallow floodplains in the flat topology" (Hough, 1984, p99). The relationship between the floodplains and topology can be seen in Map 3.1. It is clear from the map that the topology is relatively flat in this site. In accordance with the original master plan, developments preserved a buffer zone around the streams. These drainage easements were decided by the 25 year floodplain: "300 feet for primary drainage channels and 100 feet for secondary drainage channels" (see Figure 3.4) (Hough, 1984, p102).

The water system is an important natural system which includes drainage and aquifer recharge. "Thus, the development had to be designed to respond to the porosity of the soils and the character of the vegetation in order to maintain groundwater levels and substantially reduce runoff" (Forsyth, 2003, p12).

The development of The Woodlands was planned to minimize the adverse impacts on the 100-year floodplain. To make up for the effects of urbanization in a developing watershed, the stormwater management used detention storage as an alternative (Johnson and Berger, 1979). The essential method is to "provide sufficient storage and control of outflow in the upper watershed areas to negate the effects of development, releasing flow later at the same rate as undeveloped land, thus relieving and protecting downstream areas" (Johnson and Berger,1979). In upper watershed areas, detention storage is an effective way to control the storm water. However, random or unplanned development can greatly reduce the effectiveness of detention storage and may aggravate potential flood hazards in some cases (Johnson and Berger, 1979).

Natural drainage is a useful way to control and manage storm water drainage over vegetated land. This process will help natural infiltration into the ground and control the velocity of water, features which are crucial for controlling erosion and sedimentation (Hough, 1984). "Vegetated soils and woodlands provide storage by trapping and percolate water through the ground with minimum run off and maximum benefit to groundwater recharge" (Hough,1984, p90). Thus, vegetation is an important factor to recycle water into the natural system.

Retention ponds and lakes are a way of "controlling water run-off by modifying flows smoothing out peak loads by releasing water slowly to reduce the danger of downstream flooding" (Hough, 1984, p91). The retention ponds and lakes also help to replenish natural groundwater.



Map 3.1 The relationship between floodplains and the topology

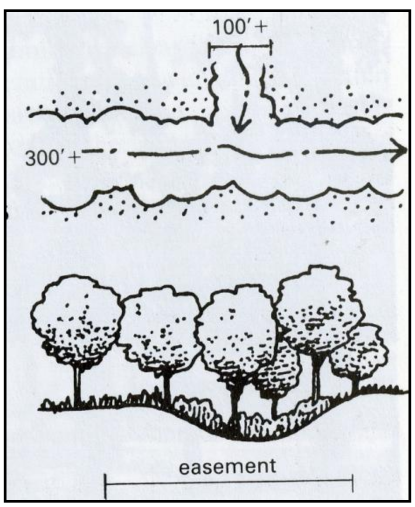


Figure 3.4 The establishment of easements in The Woodlands

Source: Hough(1984)

CHAPTER IV

RESEARCH METHOD

4.1 Research Design

This thesis employed the case study research strategy. In general, “how” and “why” questions are likely to favor the use of case study (Yin, 2003). My original research objective is to explore how the urban form adapts to the urban ecology; therefore, case study is an easy and clear way to answer this kind of question. The essence of case study is to “illuminate a decision or set of decisions: why they were taken, how they were employed and with what result” (Yin, 2003, p12). The case study does not represent a “sample,” and the goal is to expand and analytic generalization (Yin, 2003).

The primary distinction in designing a case study is between single and multiple case designs. In general, the “criticisms about single case study usually reflect fears about the uniqueness or artifactual condition surrounding the case. As a result, the criticism may turn into skepticism about your ability to do empirical work beyond having done a single-case study ” (Yin,2003, p54). So, in a single-case design, we should make an extremely strong argument in justifying the choice for the case (Yin, 2003). The Woodlands, Texas, my study case, is the very famous application of the “Design with Nature” philosophy by McHarg. The Woodlands, as an environmentally planned community, was the first of its kind (Morgan and King, 1987). In fact, The Woodlands Development Corporation completed the first Environmental Impact Statement in the United States. Although The Woodlands is persuasive for the single case study, I chose to compare another case with it to produce an even stronger effect.

4.2 Research Field

The Woodlands in Montgomery County, Texas is my primary study field. The Woodlands is the application of the “Design with Nature” philosophy by McHarg. It was the first environmentally planned community in the U.S. (Morgan and King, 1987). Thus, it is a very typical case to be focused on when analyzing how the planning should adapt to the environment.

Pearland, Texas, another field compared with The Woodlands, is also located in the Houston area with extremely flat topology similar to The Woodlands. The periodic intense rainfall brings a challenge for the drainage of storm water runoff in the Pearland area. The features of the two cities are listed in Table 4.1. From the summary of the table, we can generalize that both cities have extremely flat topology and suffer from the periodic intense rainfall.

Table 4.1 The comparison of features between The Woodlands and Pearland

Features	The Woodlands	Pearland
Regional Locations	The Woodlands is situated within the Houston–Sugar Land–Baytown metropolitan area, located 28 miles north of Downtown Houston along Interstate 45	Pearland is located about 14 miles southeast of downtown Houston and five miles south of Hobby Airport.
Topology	Located in the Gulf Coast Plaint, The Woodlands is flat, near sea level, with few slopes greater than five percent.	Surface elevations across the Pearland planning area vary from 45 feet to 65 feet above mean sea level.
Watershed	Two streams comprise the natural drainage system in the Woodlands watershed, including Bear Branch and Panther Branch, which eventually flow into Spring Creek.	Clear Creek is the principal drainage channel. Its watershed covers most of the planning area. Clear Creek, eventually empties into Clear Lake and Galveston Bay.
Soil	Many depressions exist on the flat terrain which is dominated by impermeable soils and standing water was common	Typical of the region, these dark gray soils are poorly drained, limiting private septic systems and increasing storm water runoff.
Summary	(1) Extremely flat topography (2) Periodic intense rainfall from tropical storms and thunderstorms.	

Source: City of Pearland, 1999.

4.3 Data Collection

Data for a case study can be drawn from many sources of evidence. "Evidence for case study may come from six sources: documents, archival records, interviews, direct observation, participant-observation and physical artifacts (Yin, 2003, p83). Primarily, I searched documents, archival records and the Internet in order to collect the data (see Table 4.2).

Table 4.2 Data collection

Study Variables	Data needed	Data Sources
Street Patterns	Streets (GIS) data of the Montgomery Country, Texas	(1)Texas State Data Center (2)Texas Natural Resources Information System
	Street (GIS) data of the Harris Country, Texas	(1)Texas State Data Center (2)Texas Natural Resources Information System
	Street (GIS) data of Pearland, Texas	Pearland, Texas official website
Floodplains	Digital Q3 Flood Data of the Montgomery Country, Texas	Houston-Galveston Area Council Data Clearinghouse
	Streams/creeks (GIS) data of the Montgomery Country, Texas	Houston-Galveston Area Council Data Clearinghouse
	Reservoirs and Lakes (GIS) data of the Montgomery Country, Texas	Houston-Galveston Area Council Data Clearinghouse
	Digital Q3 Flood Data of Pearland, Texas	Houston-Galveston Area Council Data Clearinghouse
	Creeks (GIS) data of Pearland,Texas	Pearland, Texas official website

The Digital Q3 Flood Data are designed for FEMA's needs to respond for disaster activities, National Flood Insurance Program activities, risk assessment and floodplain management (The Highlands Council, 2006). The data are expected to be used for various planning applications such as floodplain management, land-use planning, insurance target marketing, natural environmental analyses and real estate development. The FEMA Q3 flood coverage includes the 100-year floodplain, but detailed hydraulic analyses have not been performed; therefore, no base flood elevation or depths are shown (The Highlands Council, 2006). However, it is enough for this research objective.

4.4 Data Analysis

4.4.1 Measure Street Patterns

The research objective is to analyze the relationship between street patterns and natural drainage systems in The Woodlands. Firstly, we should identify how to measure the street pattern. Song and Knaap (2004) have illustrated how urban development patterns can be measured. Song has done a lot of work on measuring urban form, as well as how to measure the "street design and circulation systems." Song and Knaap (2004) have given several indicators for measuring street pattern:

(1) "Int_Connectivity—number of street intersections divided by sum of the number of intersections and the number of cul-de-sacs; the higher the ratio, the greater the internal connectivity

(2) Blocks_Peri—median perimeter of blocks; the smaller the perimeter, the greater the internal connectivity.

(3) Blocks—number of blocks divided by number of housing units; the fewer the blocks the greater the internal connectivity.

(4) Length_Cul-De-Sac—median length of cul-de-sacs; the shorter the length_Cul-de-sacs, the greater the internal connectivity.

(5) Ext_Connectivity—median distance between Ingress/Egress (access) points in feet; the shorter the distance, the greater the external connectivity."(Song and Knaap,2004, p27).

We can find that all the indicators above are measuring the street connectivity because connectivity is the primary purpose of any transportation network. Advocates of New Urbanist and neo-traditional planning concepts include street connectivity as a key component for sound circulation design (Dill, 2004).

Connectivity refers to the accessibility to various parts of the community and the links between neighborhoods. It is the most important indicator for displaying the functionality of street networks. The Woodlands is not a large city, so the internal connectivity is more important. I have referred to other literatures concerning the street internal connectivity and listed in the Table 4.3.

Table 4.3 The list of literatures concerning the street internal connectivity

Measure	Literature
Block length (mean)	Cervero and Kockelman (1997)
Block size (mean area) Block size (median perimeter)	Hess et al. (1999) Reilly (2002) Song (2003)
Block density	Cervero and Kockelman (1997) Cervero and Radisch (1995) Frank et al. (2000) (census block density)
Intersection density	Cervero and Radisch (1995) Cervero and Kockelman (1997) (# dead ends and cul-de-sacs per developed acre) Reilly (2002)
Percent four-way intersections	Cervero and Kockelman (1997) Boarnet and Sarmiento (1998)
Street density	Handy (1996) Mately et al. (2001)
Connected Intersection Ratio	Allen (1997) Song (2003)
Link-Node Ratio	Ewing (1996)
Percent Grid	Boarnet and Crane (2001) Greenwald and Boarnet (2001)
Grid dummy variables	Crane and Crepeau (1998) Messenger and Ewing (1996)
Percent quadrilateral blocks	Cervero and Kockelman (1997)
Pedestrian Route Directness	Hess (1997) Randall and Baetz (2001)
Walking distance	Aultman-Hall et al. (1997) (mean, maximum, percent of homes meeting minimum standard)

Source: Dill ,2004

When all the measurements available are combined, I will employ three indicators: street density, connect node ration and link-node ratio. They are the densities and ratios that are easily compared between the different cases.

(1)Street Density

Street density is measured as the number of linear miles of streets per square mile of land. “A higher number would indicate more streets and, presumably, higher connectivity” (Dill, 2004, p3). This indicator also relates to intersection density and block density.

(2)Connected Node Ratio

"The Connected Node Ratio (CNR) is the number of street intersections divided by the number of intersections plus cul-de-sacs" (Dill, 2004, p3). The maximum value is 1.0. Higher numbers indicate a higher level of connectivity.

(3)Link-Node Ratio

"Link-Node Ratio is an index of connectivity equal to the number of links divided by the number of nodes within in a study area. Links are defined as roadway or pathway segments between two nodes. Nodes are intersections or the end of a cul-de-sac" (see Figure 4.1) (Dill, 2004, p4).

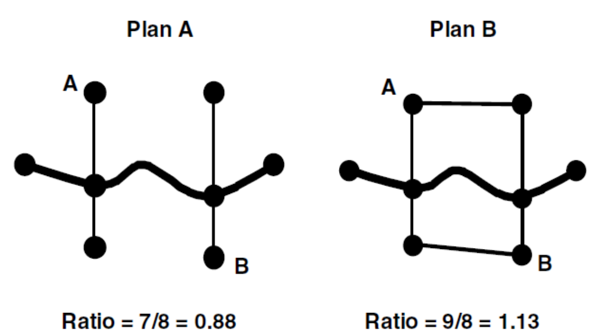


Figure 4.1 Two street plans with different link-node ratios

Source: Dill, 2004.

The internal connectivity of the street network can be measured by Geographic Information System (GIS) network analysis tools. GIS technology has made analysis of spatial patterns not a complex exercise.

4.4.2 The Analysis of Street Patterns and Floodplains

GIS technology has advantages when analyzing the spatial relationship of the variables. We can overlay the layers of streets and floodplains. In the FEMA Data Attribute Table, Zone "A" are those areas of the 100-year floodplain that are unstudied and no base flood elevations have been determined" (Richland County Planning & Development Services,2002,p1). Zone "AE" are "those areas of the 100-year floodplain that are studied and base flood elevations have been determined" (Richland County Planning & Development Services,2002,p1). Zone X500 is an area inundated by 500-year flooding. The output of the overlay map can give us a direct visual impression of their spatial relationship. I will also use statistics to bring a numeric outcome.

CHAPTER V

FINDINGS AND ANALYSIS

5.1 Measure Street Patterns

5.1.1 Introductions of Street Patterns in The Woodlands and Pearland

We can easily draw the conclusion from Figure 5.1 and Figure 5.2 that the street patterns in the Woodlands are Loops and Cul-de-sacs.

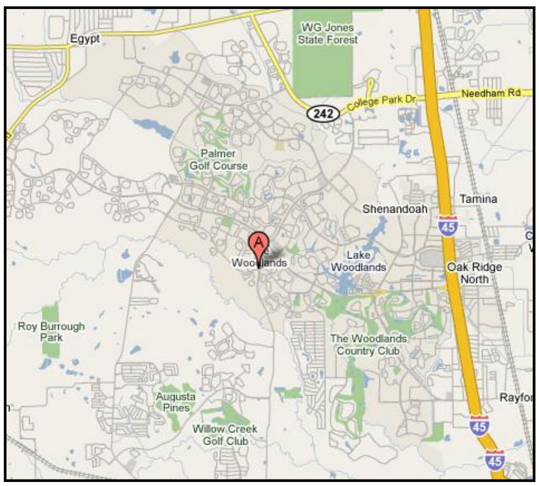


Figure 5.1 The street pattern at the town scale in The Woodlands

Source: http://maps.google.com

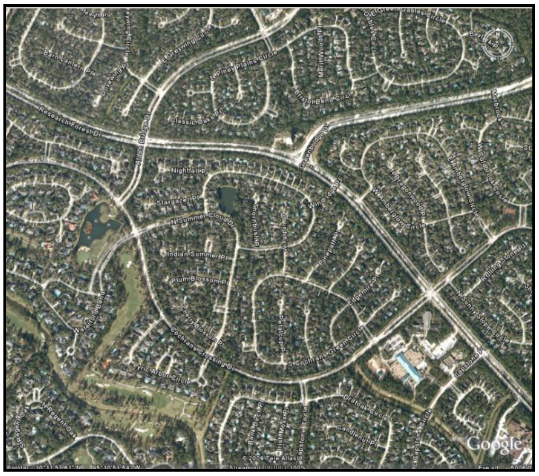
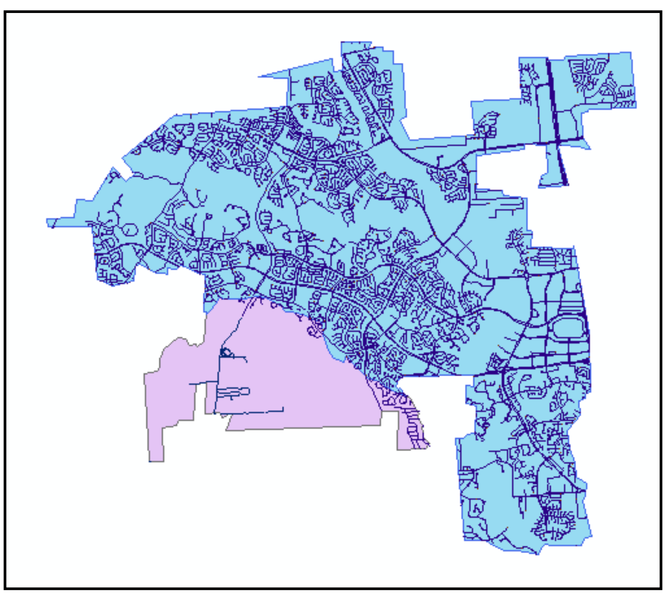


Figure 5.2 Typical street pattern details in The Woodlands

Source: http://maps.google.com

The village of Creekside Park was open in 2007 and has less street data. Thus, in the analysis, the thesis will only analyze other villages in the blue area (see Map 5.1).



Map 5.1 Street patterns in The Woodlands, Texas

From Figure 5.3 and Map 5.2, it is clear to see that most street patterns in Pearland are gridiron patterns.

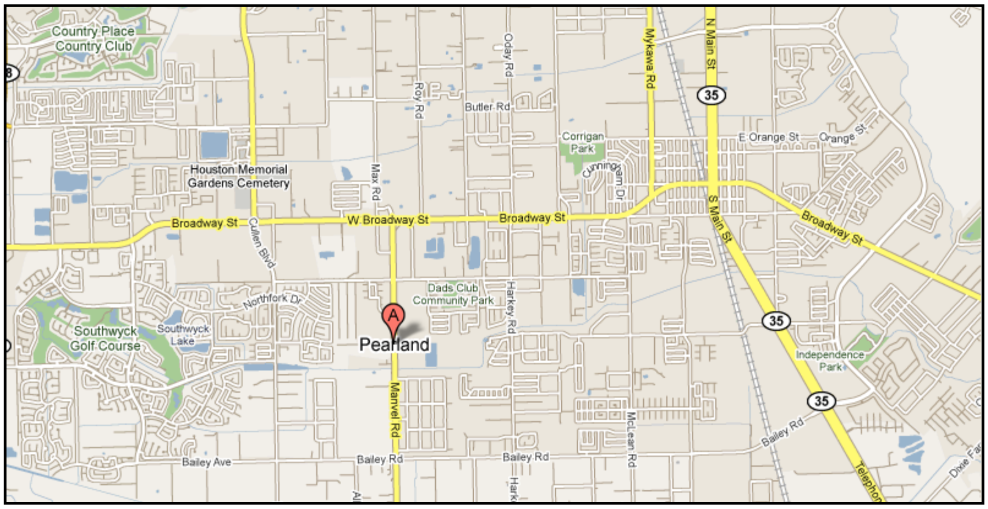
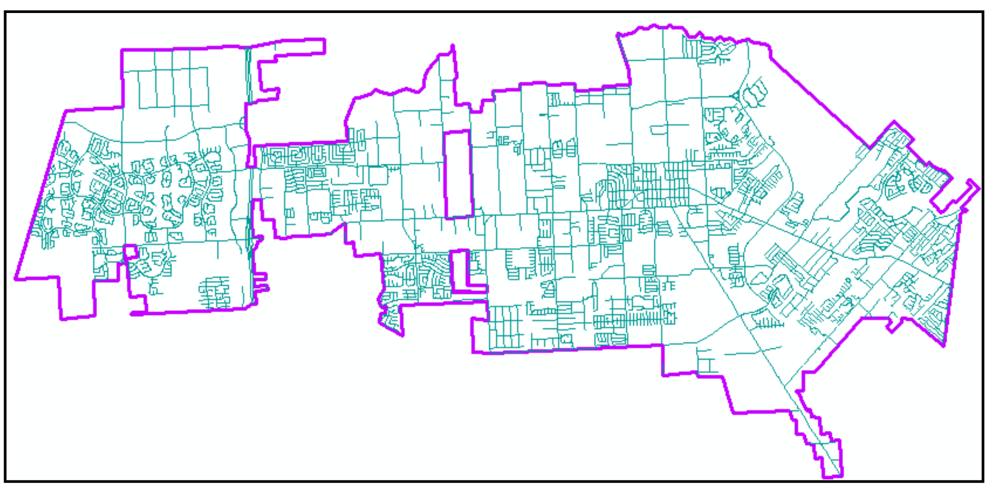


Figure 5.3 Street patterns in Pearland, Texas

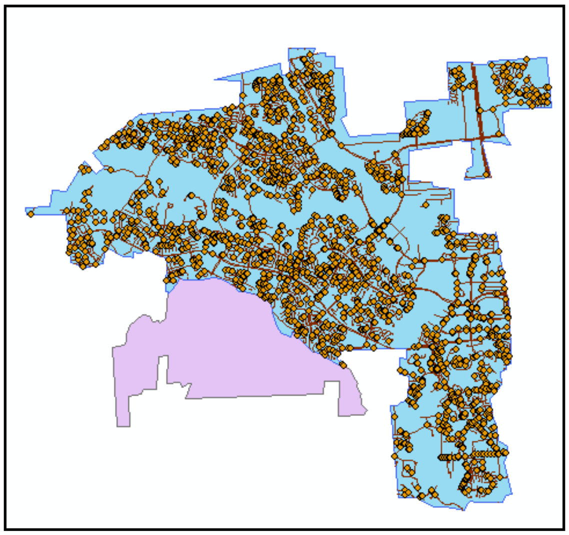
Source: http://maps.google.com



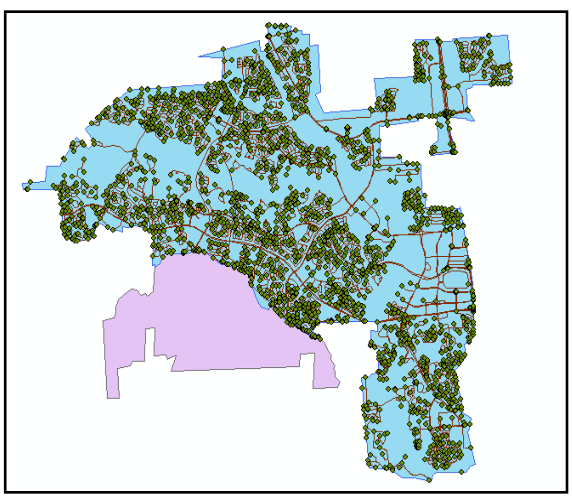
Map 5.2 Street patterns in Pearland, Texas

5.1.2 Measure Street Patterns in The Woodlands and Pearland

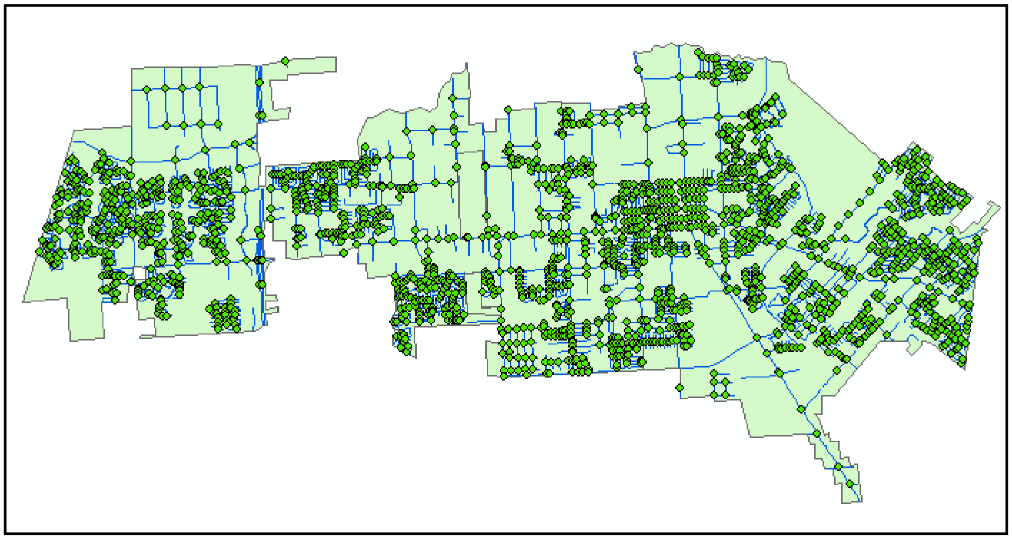
Using GIS network tool can locate all intersections and cul-de-sacs of the street pattern in The Woodlands (see Map 5.3 and Map 5.4). The same method also could be used in Pearland, Texas (see Map 5.5 and Map 5.6).



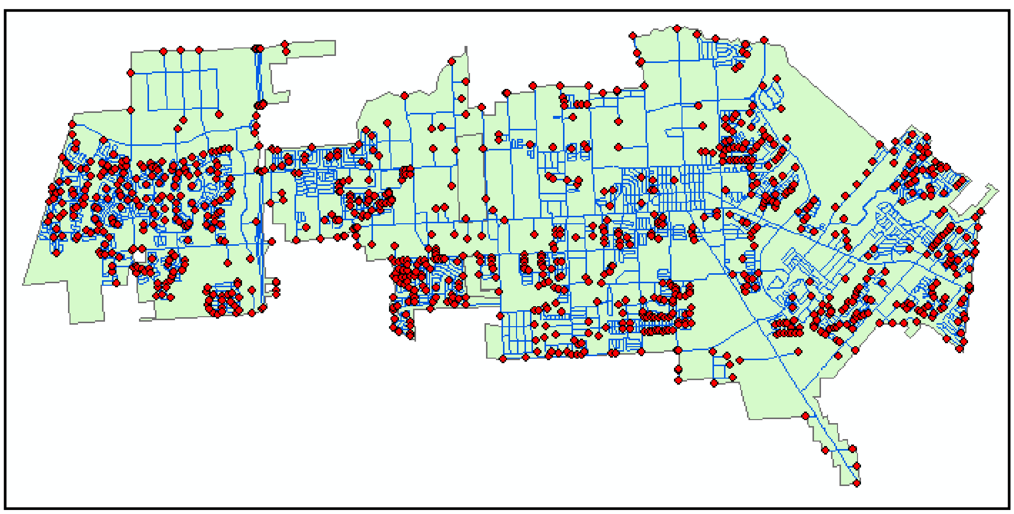
Map 5.3 The intersections of the street network in The Woodlands



Map 5.4 The cul-de-sacs of the street network in The Woodlands



Map 5.5 The intersections of the street network in Pearland



Map 5.6 The cul-de-sacs of the street network in Pearland

5.1.3 Summary

The basic data needed in measuring street patterns are listed in Table 5.1. I will use them to calculate the three indexes as follows: street density, connected node ratio and link-node ratio.

Table 5.1 The list of basic data in measuring street patterns (See Appendix 1, 2)

City	Street Length (miles)	Number of Intersections	Number of Cul-de-sacs	Number of Links
The Woodlands, Texas	471.59	1909	2371	9823
Pearland, Texas	773.19	2012	960	5256

Table 5.2 Descriptive statistics of connectivity measures applied to The Woodlands and Pearland

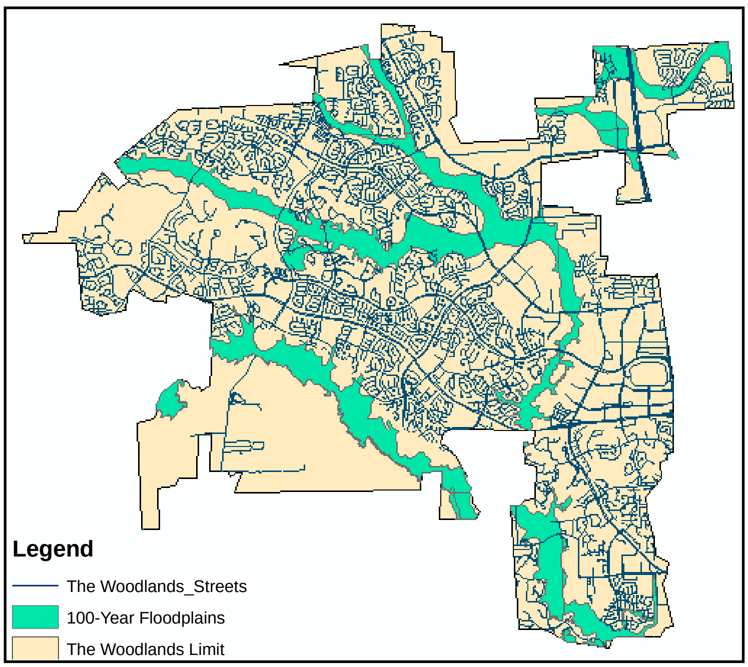
City	Street Density(miles/sq mi)	Connected Node Ratio	Link-Node Ratio
The Woodlands, Texas	**17.5**	**0.45**	**2.3**
Pearland, Texas	**22.1**	**0.68**	**1.77**

In Table 5.2, the street density and connected node ratio of Pearland is higher than that of The Woodlands, which represents that street patterns in Pearland have higher internal connectivity. The Link-Node Ratio of Pearland is lower than The Woodlands, which tells us that more loops sometimes can improve the connectivity.

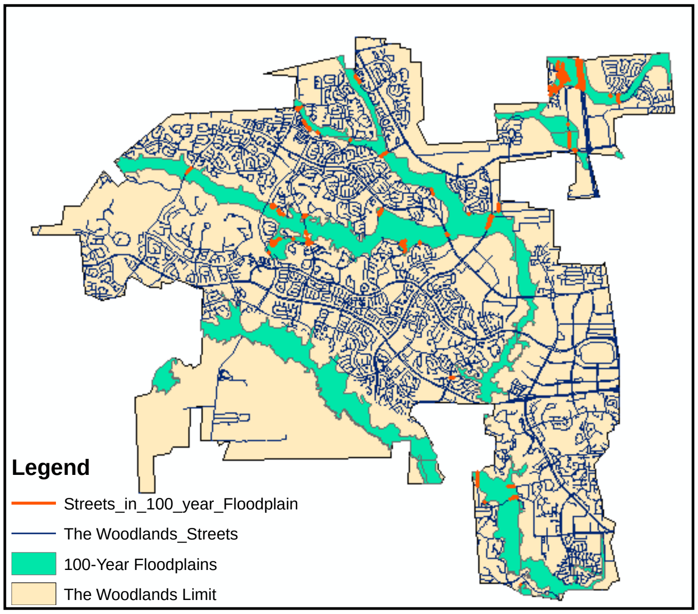
5.2 The Relationship between Street Patterns and Floodplains

5.2.1 The Relationship between Street Patterns and Floodplains in The Woodlands

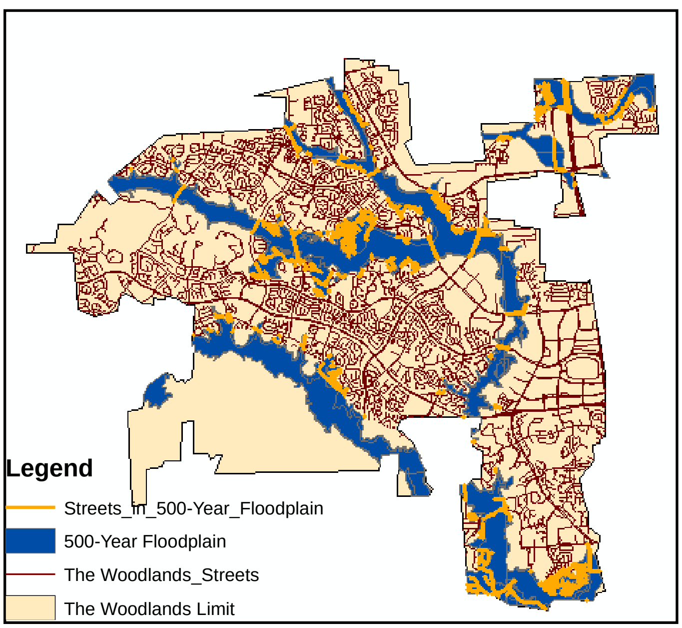
Map 5.7 shows the result after overlapping the streets layer and 100-year floodplain layer of The Woodlands in ArcGIS. Then, it is easy to highlight the streets in the 100-year floodplain (see Map 5.8). The same method was applied into analyzing relationship between street patterns and the 500-year floodplain of The Woodlands (see Map 5.9)



Map 5.7 The 100-year floodplains in The Woodlands, Texas



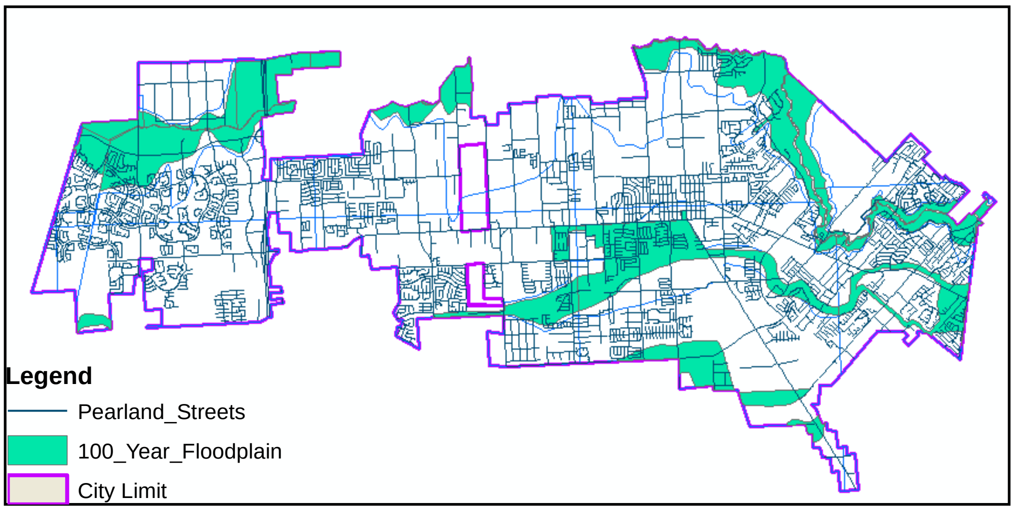
Map 5.8 The relationship between street patterns and 100-year floodplains in The Woodlands



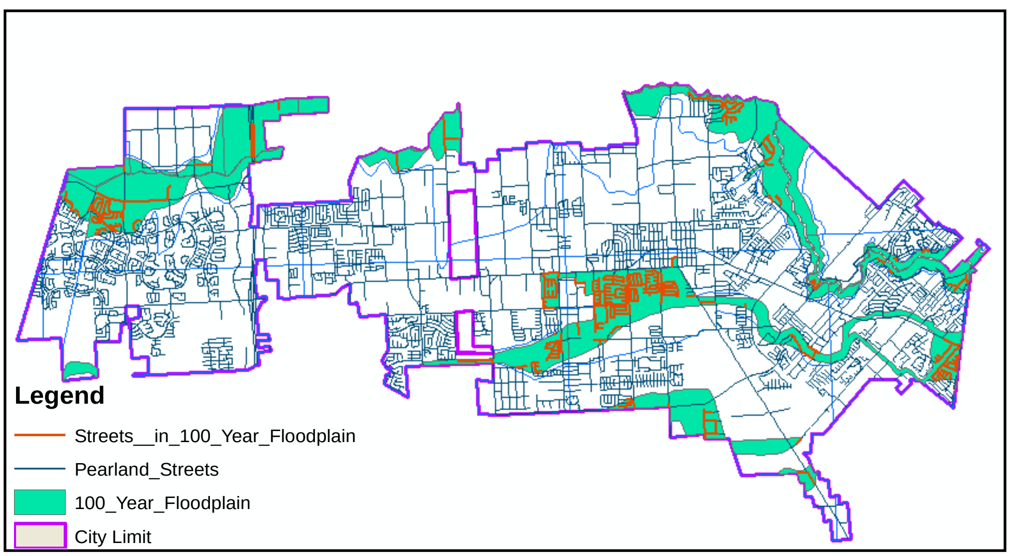
Map 5.9 The relationship between street patterns and 500-year floodplains in The Woodlands

5.2.2 The Relationship between Street Patterns and Floodplains in Pearland

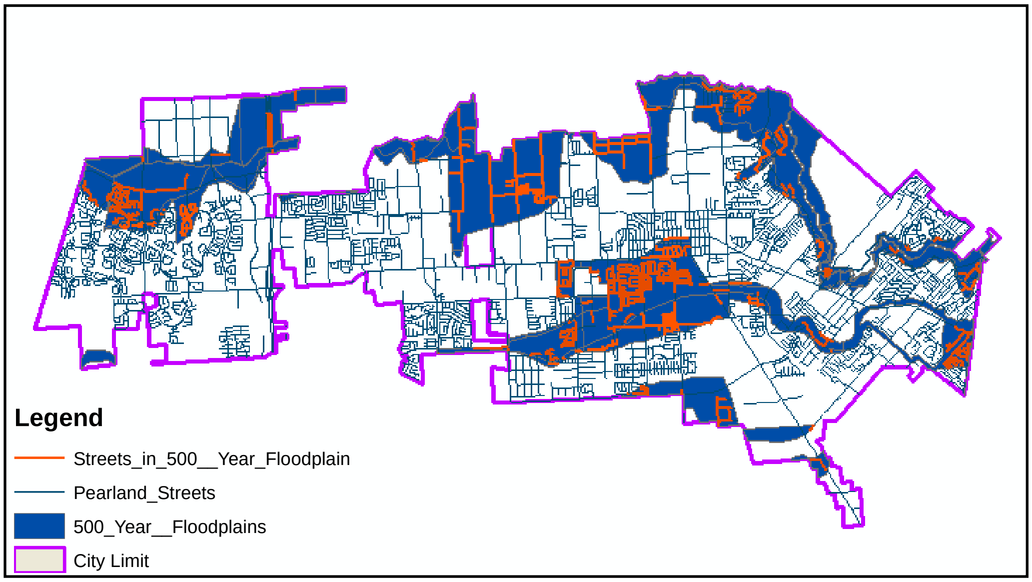
Map 5.10 shows 100-year floodplains in Pearland. Map 5.11 highlights the streets in the 100-year floodplains and Map 5.12 displays the streets in 500-year floodplains.



Map 5.10 The 100-year floodplains in Pearland, Texas



Map 5.11 The relationship between street patterns and 100-year floodplains in Pearland



Map 5.12 The relationship between street patterns and 500-year floodplains in Pearland

5.2.3 Summary

From the maps above, it is obvious to find that the streets built in the floodplains of The Woodlands are much fewer than that of Pearland. Table 5.3 specifically gives us the percentage of streets in the floodplains of each city, which makes the comparison more clear.

Table 5.3 Percentage of street length in floodplains (See Appendix 3,4)

City	Percentage of the length of streets in 100 year floodplains	Percentage of the length of streets in 500 year floodplains
The Woodlands, Texas	**1.6%**	**4.7%**
Pearland, Texas	**7.8%**	**16.3%**

CHAPTER VI

CONCLUSIONS

6.1 Research Summary

This research uses a famous ecological planning example to explore how street patterns are designed with consideration of the hydrological process. New Urbanism and Smart Growth have called for the implementation of their principles for street and circulation design, in which connectivity is an important index to evaluate the quality of the street design. In New Urban sites, more attention is on defining desirable urban forms and detailed design standards, but the use of nonstructural hazard mitigation practice is not considered as often.

After measuring the connectivity, we notice that Pearland, with grid patterns, has higher connectivity than that of The Woodlands, with loop and cul-de-sac patterns. However, through analyzing the relationship between street patterns and floodplains using GIS tools, this thesis can conclude that, in The Woodlands, the percentage of streets in the 100-year floodplains is much lower than that of Pearland. This thesis also concludes that the street shape corresponds to the boundaries of floodplains. Unlike the grid-like pattern advocated by the New Urbanists, the street pattern in The Woodlands is loop and cul-de-sac, a typical suburban pattern in the 1970s. However, it adapts to the boundaries of floodplains and protects them very well. Flood control in The Woodlands is much better than other places in the Houston area.

The floodplain protection includes minimizing fill-in floodplains and grading-in floodplains, and preserving the vegetation buffers of floodplains (Berke et al., 2009). There are two types of development management practices for floodplains: one is nonstructural practice, intending to limit or avoid development in hazardous areas; second is the structural practice to create building standards.

Nonstructural practice involves “avoiding hazard areas and other environmentally sensitive areas” (Berke et al., 2009, p450). The hazard mitigation technique for nonstructural is “environmentally sensitive area protection” involves “preventing development in floodplains and protecting flood mitigation services provided for by floodplain ecosystem” (Berke et al., 2009, p444). The Woodlands is a representative example of nonstructural practice since the planning of the city minimized the development in floodplains as can be seen in the map.

Although some streets of Pearland are in the 100-year floodplains, there may not be developments or developments may rely on the structural protection technique for mitigation of development in floodplains. However, the developments inside the 100-year flood zone are compelled to meet minimum flood elevation and the structural strengthening standards of the National Flood Insurance Program (NFIP) (Berke et al., 2009). To meet requirements, developments in flood zones need the structural practice technique. The structural protection includes “raising the elevation of buildings and infrastructure, structural strengthening and building levees and flood walls” (Berke et al., 2009, p.444). Pearland is an example of this. The streets within the floodplains require raised elevation. Sometimes, building flood control dams and flood walls is necessary.

Additionally, the lots in cul-de-sac street patterns may enclose fewer houses than long and straight grid street patterns, which could cause low density development. The Woodlands is a low density community. High density may avoid developments in sensitive areas and give more space to floodplains. However, "compact development patterns concentrate stormwater runoff rather than spreading runoff across the landscape" (Berke et al., 2009,p445). Therefore, high density increases the possibility of using structural mitigation techniques.

The New Urbanists advocate the gridiron street pattern over the loop and cul-de-sac street pattern. However, compared to conventional development, the New Urban development had not performed well in hazard mitigation (Berke et al., 2009).The New Urban development relies more on structural techniques for the mitigation of development in floodplains than conventional development (Berke et al., 2009). Nonstructural mitigation techniques have more advantages than structural mitigation techniques for flood control and the protection of the natural environment. "More nonstructural hazard techniques are likely to be adopted, and losses from flooding are likely to be lower in communities" (Berke et al., 2009, p.450).

The Woodlands is a typical example of employing nonstructural techniques through minimizing the development in floodplains. Flood control in The Woodlands is much better than other places in the Houston area.

6.2 Future Research

This thesis focuses on the floodplain because one third of The Woodlands area is in floodplains and it heavily influences the site planning. The focus of this thesis was also influence by the data available. The street pattern is one element of the city form. The research area could be extended from the street pattern to the city form, which concerns net density and mixed use as well as the street pattern.

The Houston area is not the only area that needs flood control in the United States. In the last ten years, the losses from flood hazards in the United States have increased radically (Burby, 2001). There are two important reasons for the increasing flood hazards: first, flourishing urban developments have occurred in areas and brought great risk from flood hazards; second, “local governments have not done an adequate job of steering development away from flood-hazard areas or of seeing to it that appropriate hazard mitigation measures are employed in new construction” (Burby, 2001, p111). The costs of mitigation are not as visible as constructing schools or roads, therefore, few local governments are eager to improve development management to reduce flood hazards (Berke et al., 2009). However, it is imperative to recognize that significant losses could be avoided through reasonable planning and sound development management (Berke et al., 2009).

Thus, options for introducing the flood hazard mitigation and environmental protection strategies into city form will be an exciting topic.

Berke, Song and Stevens have discussed the integration of hazard mitigation into New Urban and Conventional developments. They indicate the smart growth code provides guidelines for making new urban development. Detailed development standards are adapted to six zones from urban core to rural perspectives (Berke et al., 2009). A general list of "sensitive areas to be protected is provided by for rural zones, but no attention is given to hazards in urban and rural zones" (Berke et al., 2009, p442). Their research is a new and interesting topic, which offers a broad vision. Comparing the smart growth code and ecological design guidelines drawn by Mcharg in The Woodland planning is another interesting topic for future research.

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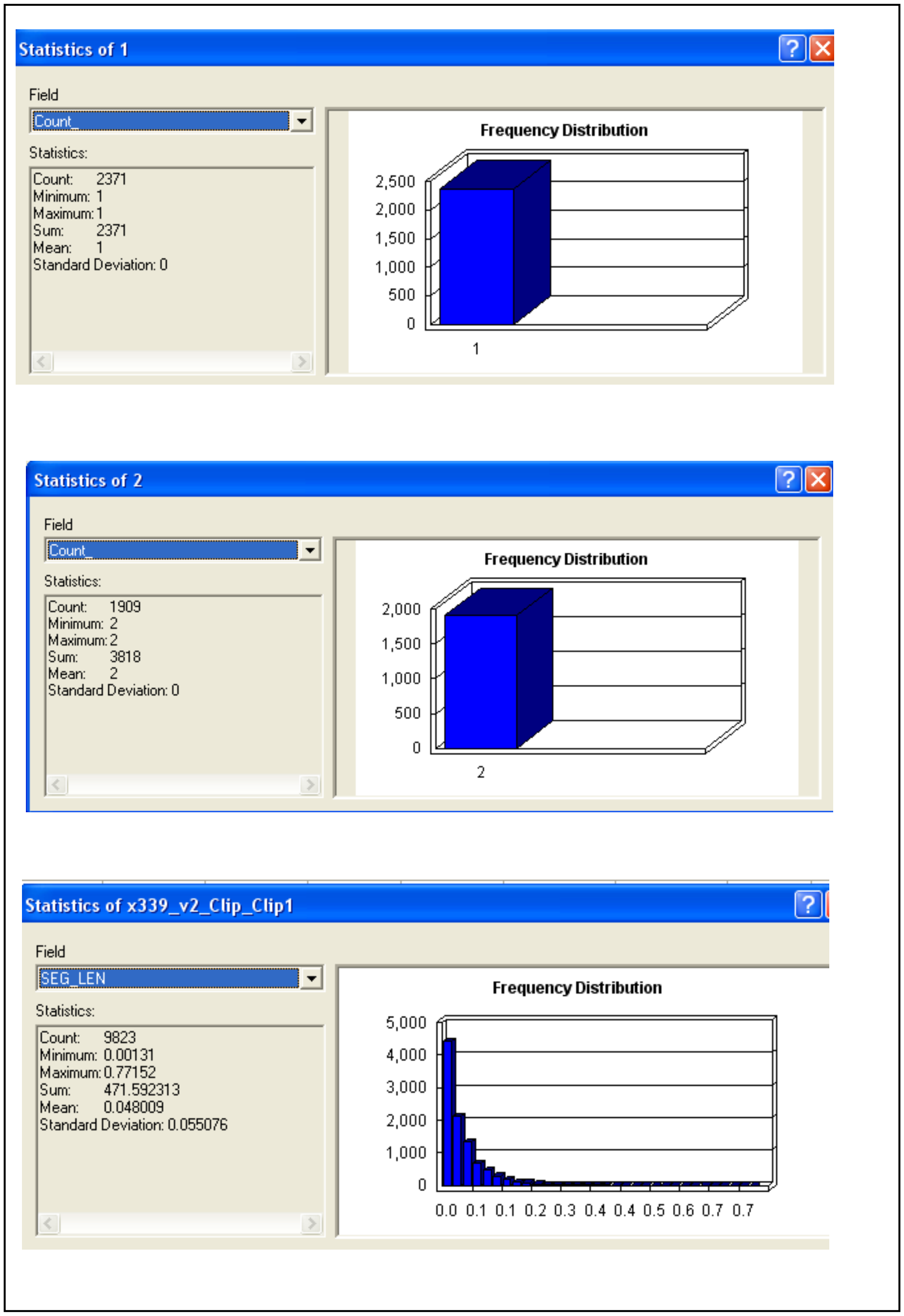
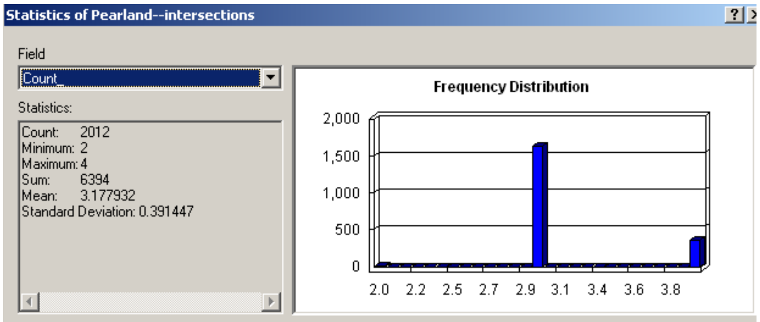
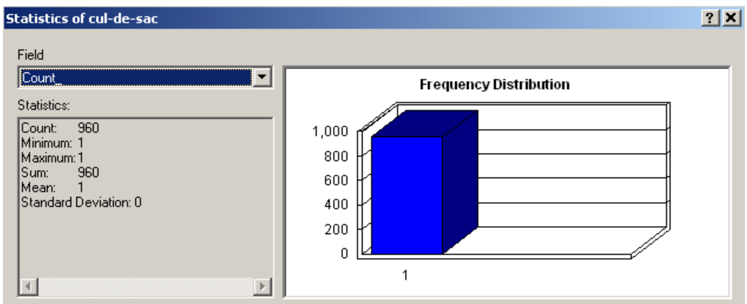
APPENDIX

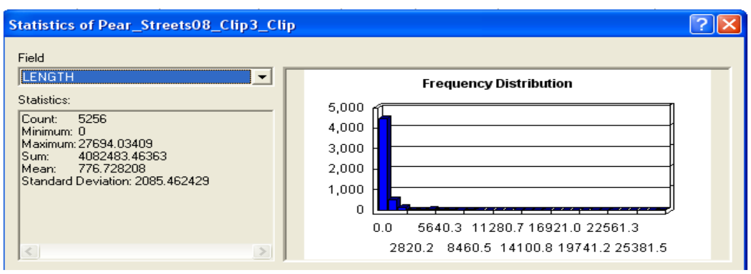
APPENDIX 1 The Statistics of Measuring Street Patterns in The Woodlands



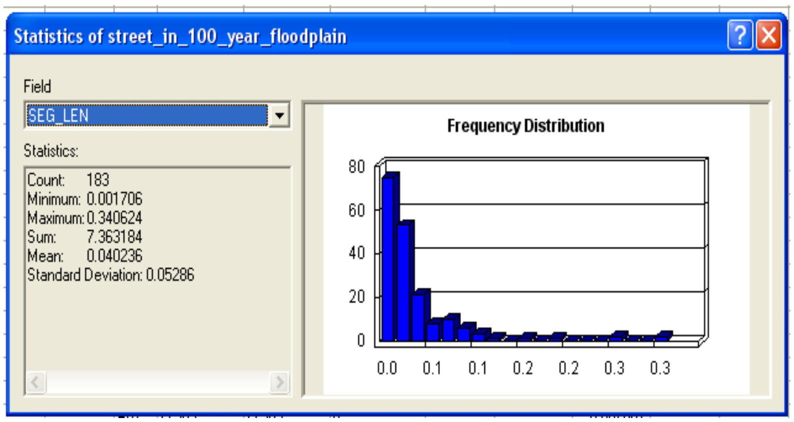
APPENDIX 2 The Statistics of Measuring Street Patterns in Pearland

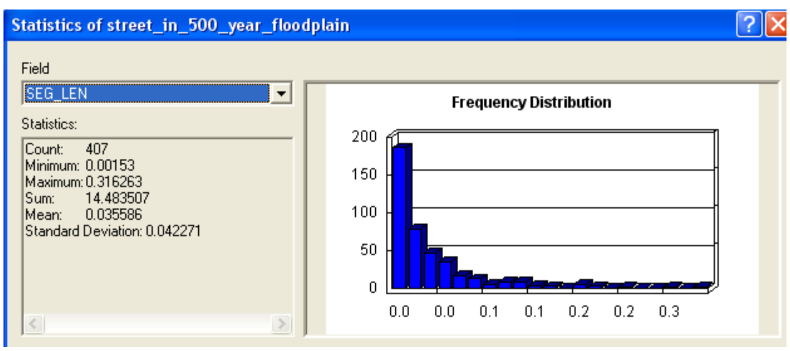


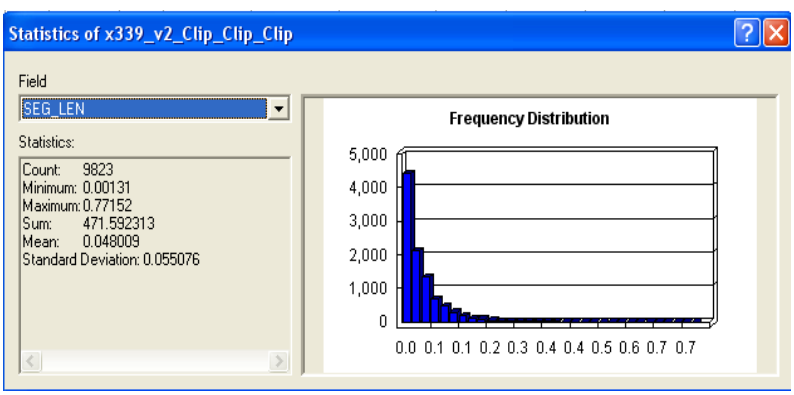




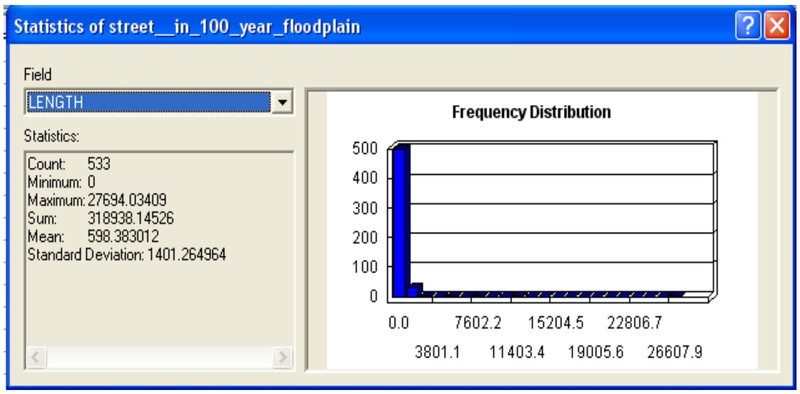
APPENDIX 3 The Statistics of the Relationship Between Street Patterns and Floodplains in The Woodlands

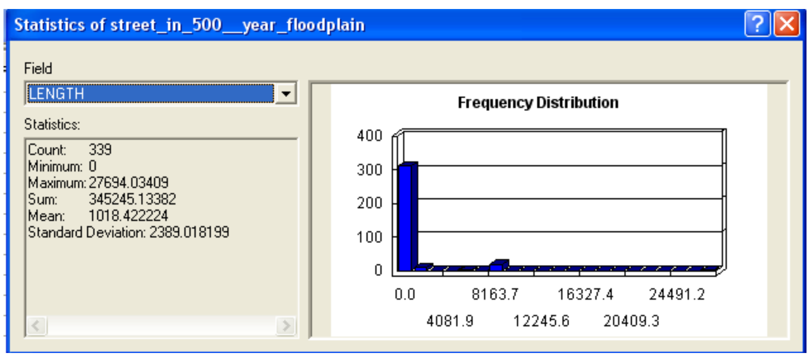


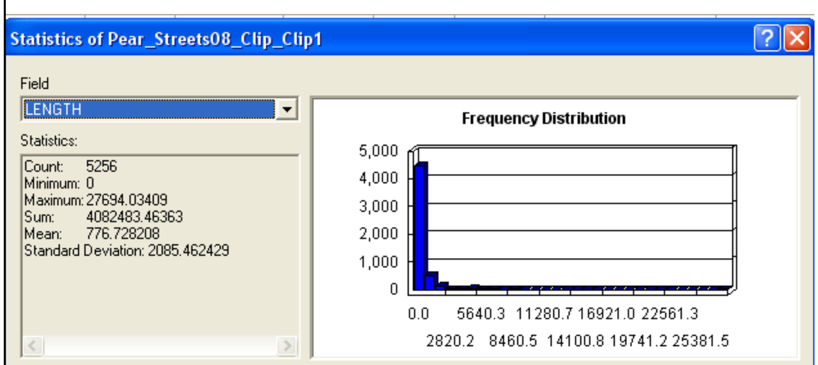




APPENDIX 4 The Statistics of the Relationship Between Street Patterns and Floodplains in Pearland







VITA

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